GEOLOGICAL TIME

COMMITTEE ON MEASUREMENT OF GEOLOGICAL TIME IN INDIA

Council of Scientific & Industrial Research
New Delhi
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I

Introduction

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Modern astronomical and astrophysical research has so extended the concept of cosmic time—thousands of millions of years from the beginning of our planet, Earth—that it is beyond the comprehension of the average human mind. Whichever of the current hypotheses of the origin of planets and of the solar system we may accept, whether they originated from the condensation of a primitive nebula, or through growth by accretion of cosmic matter—planestesimals—falling from space, their origin goes back into an antiquity that is unimaginable according to human standards of time. Speculating about the age and origin of our Earth, the eighteenth century English geologist, Hutton, dismissed the problem by saying "We can discern no vestige of a beginning, no prospect of an end". But modern science is disposed to take a more serious view of the problem and does not approve of hazy and nebulous concepts about a great event, the birth of the Earth, in the history of the universe. It demands more exact and precise methods and the use of instruments and yardsticks with which to measure the duration of ABSOLUTE TIME.

It is an elementary lesson of geology that the earth's surface is mobile and that it has witnessed, in each succeeding geological age, great revolutions such as disappearance of continents by submergence underneath the oceans; emergence of new land masses from the sea to form continents, plateaus and mountains; wearing down of elevated lands to sea level by atmospheric weathering and other geological agents; eruption of volcanoes; earthquakes; and secular elevations and subsidences of the crust. These forces of nature act so gradually and imperceptibly—the same forces are acting today—that their final accomplishment takes vast aeons of time. Nature acts slowly; it draws unlimited cheques on the bank of Time.

Geologists of the past century discovered in the operations of several natural agencies acting on the earth a coefficient which, on the principle that *the present is the key to the past,* enables us to obtain some approximate idea of the lapse of time since our earth began to have its separate existence as a member of the solar system.

These calculations, however, gave indications of *relative* time and not *absolute* time. Though no finality was claimed for the estimated figure for the age of the earth arrived at by these methods (outlined below), they at least gave some idea about the minimum duration of time that has elapsed since the earth acquired its solid form and the division of its surface into land, sea and air—the lithosphere, hydrosphere and atmosphere in the learned language of science.

Geologists based their calculations in estimating past Time on the rates of working of natural processes, such as atmospheric weathering, denudation by river, sea and glaciers, the rate of deposition of sediment on the sea-floor, etc. These supply a denominator for the following.

(1) *Thickness of sediments in the earth's crust*—The crust is over 50 miles in thickness, of which at least 10-15 miles of the outer circumference is composed of stratified sedimentary rocks resting layer upon layer. At certain favourable sites, we observe piles of stratified rocks, as in the Himalayas, Alps and other mountain systems, consisting of a succession of many thousands of feet of bedded sedimentary rocks, sandstones, shales, limestones, etc., belonging to past periods of geological history. In the Tibetan zone of the Himalayas, clearly exposed at the back of the central snowy ranges, we see marine sedimentary strata in a number of natural sections, which, when pieced together, have an aggregate thickness of over 50,000 feet, belonging to only nine out of the sixteen periods of geological history. The time taken for the formation of such thickness of sedimentary beds can be calculated from the observed rate at which sediments are deposited on the seafloor. The rate of deposition of sediments on the floor of the sea (which on consolidation, in time, turn into sandstones, shales, limestones, etc.) is generally taken to be about one foot of deposit in 3,500 years. This gives roughly 175 million years (m.y.) for only a section of the geological record.

(2) *The rate of evolution of life on the planet*—The rate at which life evolved from primitive animals and plants inhabiting the primeval world of the earliest recorded rock-system (the Cambrian) to the present (the Pleistocene) highly developed animal and plant population of the globe, furnishes data for measuring geological time. Palaeontologists have observed the extremely slow rate of evolution of individual species and genera in fossilised remains entombed in strata of past geological systems. As a succession of countless species and genera of animals have come on the stage in the course of ages, evolved to their maximum development in diversified forms belonging to higher and higher genera, families and orders and become extinct, to be succeeded by other species, genera and orders, the time required for their evolution is considered by geologists to be as long, if not longer than that calculated from the rate of deposition of the stratified crust. From the primitive polyp and trilobite of Cambrian times to Man, coming at the head of mammals, at the end of the Teritiary era of geology, is a wide gulf, bridged by unnumbered extinct animal forms. From the rate at which organic evolution progresses at the present day palaeontologists as well as biologists have estimated at

least 300–500 m.y. for this change in the organic creation to be brought about.

(3) *The amount of salinity in the ocean waters and its annual growth*—This method is based on the assumption that the primitive oceans, which emerged from the condensation of atmospheric vapours in Archaean times, were devoid of any appreciable salt (sodium chloride) content. The rate at which the rivers of the world discharge annually into the oceans their quanta of sodium salts dissolved out of the crust is measurable. As accurate determinations of the salt content of the waters of principal rivers of the world annually discharged into the oceans have been made, it is easy to calculate the period of time during which the oceans round the continents have been accumulating their present amount of salt, especially sodium chloride, which is the salt that is retained by the sea and not precipitated in the open sea basins. This calculation gives about 100 to 200 million years as the probable length of geological time since the Archaean. This method, however, is based on several hypothetical assumptions and unverifiable data which render it liable to serious errors in calculation.

(4) *The uranium-lead and helium ratio methods*—The above three methods are now out-moded as they give only a relative dating for a rock, mineral or fossil, in terms of geological time. The discovery of radioactivity at the beginning of the present century has placed in the hands of the geologist a new and more precise weapon for attacking the problem of Absolute Time. The discovery that uranium and thorium break up into other elements through spontaneous disintegration, producing as a final residuum, lead, the conversion taking place at a definite and measurable rate, has led to some revealing facts about the age of rocks of different geological systems. These methods, based on the investigation of lead-uranium ratio and the helium ratio of uranium-bearing minerals occurring at different levels in the earth's crust, are described in the sections that follow and are, therefore, not detailed here.

In India, large areas of the Himalayas and Deccan are covered by rock formations that are devoid of identifiable fossils. Their geological age and correlation with distant rock-systems in India and abroad is a matter of uncertainty and speculation. There are widespread pre-Cambrian and Palaeozoic formations, devoid of any geological data regarding their chronology, order of succession and relative position in the Standard Stratigraphic Column. These formations occur at several horizons and positions of critical importance in the aggregate thickness of India's sedimentary record. They have not been deciphered by purely geological methods, but it is probable that they may possess radioactive minerals or detrital plant or animal fossil micro-organisms which might enable their age and position to be determined, by the microscopic technique that modern geology has devised.

Investigations on the measurement of geological time in India, besides being helpful in the solution of many geological problems, are likely to help mineralogists and prospectors in locating mineralised zones of economic value and in tracing the consanguinity of the widely scattered mineral-bearing pegmatite veins and dykes through

wide stretches of the country. The quantum of research on this subject in India has not been significant, partly due to certain technical difficulties and largely due to lack of appreciable co-operation amongst geologists, physicists and chemists.

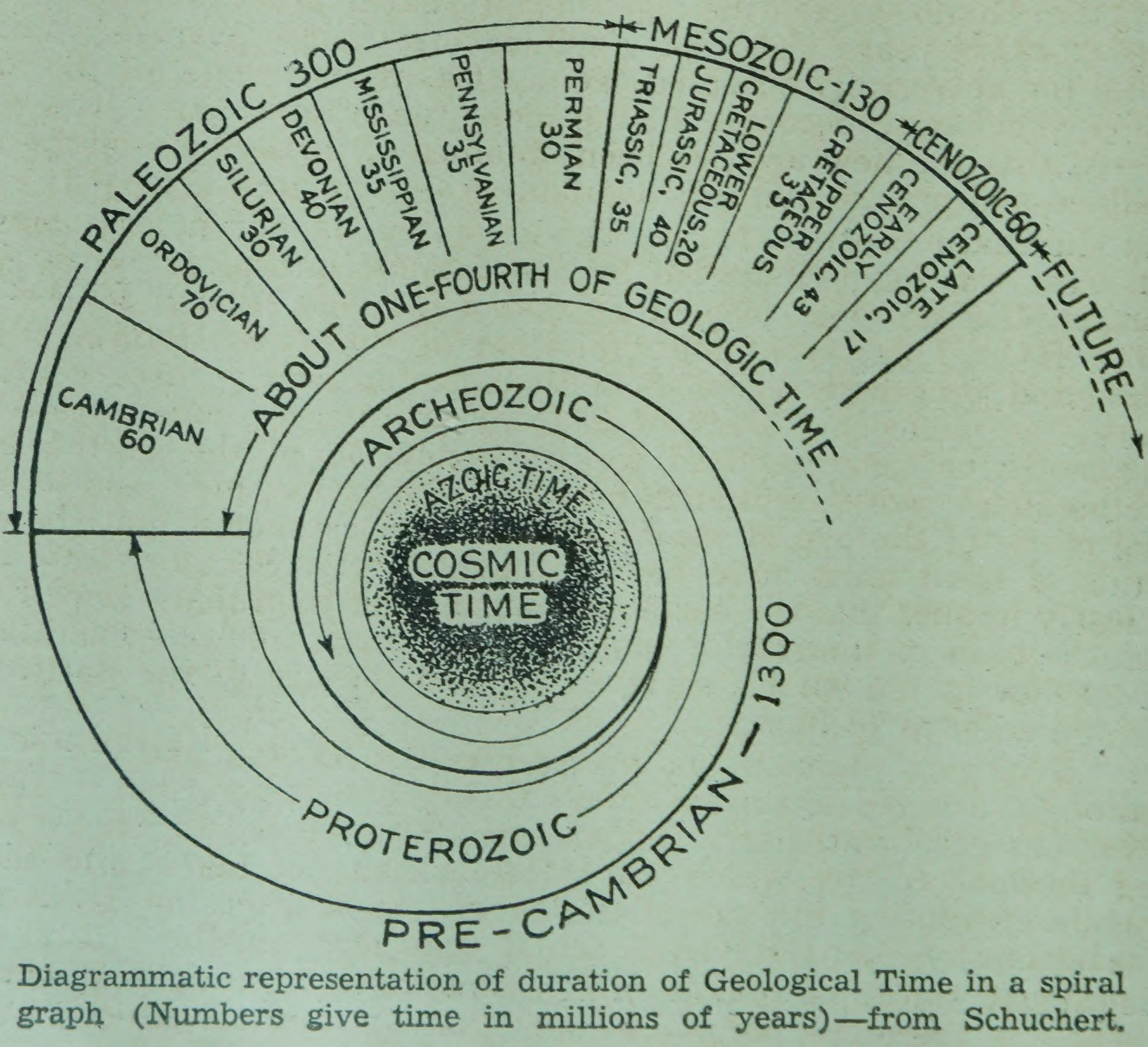
Recognising the importance of geo-chronological studies, the Council of Scientific and Industrial Research constituted, in 1947, a Committee on Measurement of Geological Time in India to organise, systematise and finance schemes of research on the subject. On the recommendation of the Committee, the Council approved a plan for initiating the following research schemes in four institutions:

(1) Investigations on the uranium-thorium and radium contents of Madras granites, gneisses, etc.—Professor C. Mahadevan, Geology Department, Andhra University, Waltair and Professor R. S. Krishnan, Indian Institute of Science, Bangalore.

(2) Chemical analysis of radioactive minerals from Gaya and Nellore Districts—Professor P. B. Sarkar, University College of Science, Calcutta.

(3) Palaeobotanical research—Birbal Sahni Institute of Palaeobotany, Lucknow.

The work carried out in these Institutions is recorded in technical papers and reports. For the benefit of the lay public, a popular account of the meaning and significance of geological time and a review of the work done under the Committee is given in the pages that follow.



Diagrammatic representation of duration of Geological Time in a spiral graph (Numbers give time in millions of years)—from Schuchert.

II

Investigations on the Age of Madras Granites and South Indian Rocks

Prof. C. MAHADEVAN

Andhra University, Waltair

Man, ever since he has evolved into a conscious individual, must have always wondered as to how old was the mother Earth. This elemental curiosity in him had manifested itself in the devising of the various systems of chronology. According to the time-scale evolved by the Hindu sages, the age of the Earth was computed to be 1,97,29,49,054 years (1953 A.D.) which, surprisingly enough, coincides with the universally accepted age of 2,000 million years for the Earth. This coincidence becomes all the more remarkable when it is considered that the new age has been obtained with the help of the most refined and precise methods available to the modern geologist.

In sharp contrast to the Hindu system of chronology, western thought was long influenced by the Biblical interpretation of Archbishop Ussher (1581-1656) that the world was created in the year 4004 B.C. This "cramping limitation of time", as Holmes puts it, hindered progressive geological thought for nearly three centuries, until the pioneering work of Hutton conclusively demonstrated the enormity of time required for the evolution of the Earth's crust. Subsequent work oscillated between giving too high and too low estimates of the age of the Earth. Darwin estimated that the chalk hills of Kent must have been formed at least 300 m.y. ago, which clearly implies that the earth was much older than that. Lord Kelvin on the basis of the rate of cooling of the earth from consideration of heat-flow at the earth's surface, deduced the age of the Earth to be of the order of 20-40 m.y.

Geological opinion, as represented by Giekie and Perry, was strongly arrayed against Kelvin's theory and it persisted in spite of Kelvin's great authority. Apparently there seemed to exist a source of thermal energy which Lord Kelvin had not taken into account while computing the age of the earth. Soon after the discovery of radioactivity, Lord Rayleigh found that most of the crustal rocks contained traces of radium which constitutes an unfailing source of heat. It, therefore, became evident that the thermal structure of the

earth could be sustained without drawing any appreciable energy from the internal heat of the core, as the heat escaping from the earth's crust is continuously being recouped by the thermal energy generated by the decay of the radioactive elements present in the crustal rocks.

Subsequent workers like Joly, Sollas, Becker and Conway tried to compute the age of the oceans from considerations of salinity. The method is based on the simple principle that the total salt content of the oceans divided by the amount of salt added annually to the sea through the medium of rivers and other forms of drainage, gives the age of the oceans. The ages so deduced vary from author to author—Joly, 80-100 m.y.; Sollas, 80-150 m.y.; Becker, 60-65 m.y.; and Conway, 250 m.y.

General Considerations

The accurate measurement of the immense periods of geological time requires a process which can fulfil three important conditions: (i) it must have been in operation ever since the beginning of the geological period or event under study, (ii) its present rate and the results it has produced must be capable of accurate measurement, and (iii) its rate through the period should not have varied. The only process known that can fulfil these stringent conditions is the natural phenomena of the decay of radioactive elements.

(a) *Decay of radio-elements of the uranium-thorium series*—The two uranium isotopes (U or U^{238} and AcU or U^{235} decay with the generation of a solid end-product lead (Pb^{206} and Pb^{207}) and gaseous end-product helium.

$$U^{238} \rightarrow Pb^{206} + 8\,He$$
$$U^{235} \rightarrow Pb^{207} + 7\,He$$
$$U^{232} \rightarrow Pb^{208} + 6\,He$$

Two methods of measurement of geological time flow from this. If a mineral containing radio-elements occurs in a certain formation and if its uranium, thorium and lead contents can be accurately determined, its age can be readily calculated, assuming the decay constants. A refinement in this method is a study of isotope ratios. It is now possible to determine the age of a radioactive mineral from the ratio of Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{208}/U^{232} and Pb^{207}/Pb^{206}. Pb^{206} is the lead isotope generated by the parent element U^{238}; Pb^{207} is the lead isotope produced by U^{235}; and Pb^{208} is the lead isotope produced by U^{232}.

In the case of gaseous end-product helium, the age is determined from the data on the total helium content of the specimen and the rate of helium production.

It is also possible to determine the age from a study of the pleochroic haloes which are the spherically symmetrical colorations met with in certain minerals like mica and cordierite.

(b) *Decay of rubidium*—An isotope of the element rubidium decays into strontium with the emission of β-rays. This decay process has been found helpful in computing the ages of minerals like lepidolite and microcline which are characterised by high rubidium content. The

oldest mineral examined by this method is the Manitoba lepidolite which has given an age of 2,000 m.y. This age agrees with that obtained by the lead method.

(c) *Radioactive transformation of potassium*—A new method for the measurement of geological time has been provided by the radioactive properties of an isotope of potassium (K^{40}). It decays into calcium (Ca^{40}) with the emission of β-rays and also gets itself transformed into an isotope of argon (A^{40}) by electron capture. Preliminary work on potassium minerals like orthoclase, microcline and sylvite by workers abroad has given very interesting results and there are good reasons to believe that this method may ultimately prove superior to all others. It may be mentioned in this connection that this method has given great fillip to a new technique in mass-spectrography—the isotope dilution technique.

(d) *Radioactivity of C^{14}*—The radio-isotope of carbon (C^{14}) is now making possible the precise measurement of ages of relatively low order. This method which was initially applied for the measurement of archaeological ages has been further improved to compute the ages of recent and late tertiary minerals.

(e) *Non-radiogenic isotopes*—Recent years have seen the origin and phenomenal progress of a new branch in geology—the istope geology. Apart from the radioactive isotopes which have been extensively studied during the last two decades, there exist several non-radiogenic isotopes which provide a most fascinating subject for study. The have been found to have immense importance in the solution of several geological problems which include the measurement of geological time.

Detailed work on three radioactive minerals of South India—samarskite from Nellore, allanite from Madura and monazite from Travancore was taken up. These investigations included the determination of physical and optical characters, chemical analysis with special reference to rare elements, autoradiographic studies, etc.

Age of the Eastern Ghats Pegmatitic Cycle

The age of the Eastern Ghats pegmatitic cycle was a subject of controversy. Prof. Arthur Holmes, the eminent geologist, while trying to figure out the chronologic position of the Eastern Ghats, pointed out the enormous discrepancy in the ages given by Sarkar and Sen Sarma (830 m.y.) on the one hand and Karunakaran and Neelakantam (1,550 m.y.) on the other for the Eastern Ghats pegmatitic cycle. The controversy led to a study of the three radioactive minerals from South India, namely, samarskite from Nellore, allanite from Madura and monazite from Travancore. The investigations included the determination of physical characters, chemical analysis with special reference to rare elements, autoradiographic studies, etc. On the basis of investigations on Nellore samarskite, the age of the Eastern Ghats pegmatitic cycle was computed to be 1,600 ± 50 m.y., which is in agreement with Prof. Holme's estimate. It was shown that the discrepancy in the age of the formation given by Sarkar and

Sen Sarma could be explained on the basis that the specimen of radioactive mineral samarskite which they had analysed, had been drawn from the Gaya group of minerals which are of much younger age (955 $\pm$ 40 m.y.), as had been later suggested by Nandi and Sen. The discrepancy was thus satisfactorily explained. The following tentative Archaean correlation Table has been suggested :

Vindhyan

Unconformity

Delhi Cycle = 735 m.y.

Unconformity

Satpura Cycle 955 $\pm$ 40 m.y. (= Upper Shillong Series)

Unconformity

Eastern Ghats Cycle (1600 $\pm$ 50 m.y.) (= Aravalli ?)

Unconformity

Dharwar Cycle

Unconformity

Older Gneissic Complex

In the case of allanite from Madura, evidence has been collected to show that the specimen is metamict and is hence of dubious value for purposes of age determination.

The radioactivity data on the Kolar Gold Field rocks, when studied in conjunction with relevant petrological and structural information, have led to very interesting conclusions regarding the distribution of radioactivity of different levels in the Kolar Gold Field mines. It has been shown that (i) the radioactivity of schists and dykes increased with depth, (ii) the β-activity curve of quartz veins is irregular, the histogram showing maxima when the quartz veins are feebly radioactive, (iii) the mica-pegmatites show the highest radioactivity, and (iv) the radioactivity of pegmatites is variable but has no relation with depth.

Attempts have been made to extend the work to α-activity measurements and Alpha-Helium Age measurement by Evan's direct fusion method.

Radioactivity of charnockites and associated rocks—The petrogenesis of charnockites, an interesting group of rocks with a fairly extensive spread in India, has been the subject of a great controversy during the last few decades. An attempt has been made to examine this problem from a new angle — the radioactivity distribution. Representative specimens of charnockites and associated rocks, drawn from Ananthagiri, Kondapalli, Pallavaram and Trichinopoly areas, which are roughly spaced at intervals of about 200 miles, were examined for their radioactivity. The data in conjunction with relevant geological informaton, revealed that the radioactive content of a rock suite of a particular area is intimately related to its petrogenitic history. In the Ananthagiri area, where the manifestations of the processes

of granitisation are clearly discernible, the radioactivity of charnockites, both individually and collectively, is markedly high. On the other hand, in the Kondapalli area where magmatic processes have played a predominant role, the radioactivity is generally low. The Pallavaram and Trichinopoly groups of charnockites are characterised by intermediate radioactivity, which is in keeping with their petrogenetic history.

Radioactivity of ocean bottom sediments—Representative specimens of snapper and core samples collected from the sea-floor off the Gangetic delta, along the east coast, down to Madras were examined for their β-activity. One group of sediments collected at suitable intervals off Visakhapatnam coast was studied with particular reference to the distribution of radioactivity with well defined zones of depth and sedimentation. A zonal pattern has been delineated on the basis of the radioactivity and has been correlated to the constitution of the sediments. The traces of radioactivity minerals like monazite in the black sand concentrates of the Visakhapatnam coast appear to be responsible for the high radioactivity of the near shore sediments.

The radioactivity of the deep sea sediments is markedly higher than any other group of sediments. Their potentialities as source of radioactive elements have been examined to some extent.

The distribution of the radioactivity in the deltaic sediments appears to be influenced by the nature of the geological formations in the drainage basin of a river responsible for the sediment and hydrographic conditions prevalent there.

The following investigations are in progress :

(1) Measurement of the ages of some Indian lepidolites by Rb-Sr method. Extension of this method to biotites and microclines rich in rubidium.

(2) Determination of the ages of some radioactive minerals (allanite from Chhota Nagpur and Anakapalli; monazite from Mewar and Bangalore, samarskite from Nellore) and the interpretation of their ages.

(3) Measurement of the radioactivity of the important rock types of South India, with particular reference to the interaction zones.

(4) Fabrication of the apparatus for the Alpha-Helium method of measurement of age.

III

Age Determination of Crustal Rocks by Radioactivity Methods

Prof. R. S. Krishnan

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Geology impresses on us the idea of the immensity of geological time. There are unmistakable evidences of at least ten major orogenic cycles each involving:

(a) thick accumulations of sediments and volcanic lava on a subsiding crustal bed;

(b) formation of geosynclines and their intense compression, resulting in crumpling and folding and accompanied by metamorphism of rocks and granitization; and

(c) general uplift of the belt and wearing away of exposed portions by peneplation.

In every continent, the oldest rocks are the metamorphosed sedimentary rocks and these merge into reorganized rocks, such a gneiss or the sediments being obviously derived from the weathering of older rocks. Some granites themselves have been formed by the process of granitization taking place in the older sedimentary deposits, both primary and altered, under conditions of intense pressure and high temperature. Thus, however far we proceed like this, to quote Hutton, "we find no vestige of a beginning."

The determination of the ages of crustal rocks provides a fascinaing field for research. The usual expression "unchangeable as a rock" is not so correct after all; the refined instruments of the geophysicist perceive an age betraying the geological clock in every stony fragment of the terrestrial crust. This natural clock is represented by the minute amounts of radioactive elements, which are present in every rock, and which are subject to slow spontaneous radioactive decay.

Methods based on radioactivity are the most accurate ones available for the measurement of geological time. This is because the process of radioactivity fulfils the following three important conditions:

(1) It is in operation since the beginning of geological period;

(2) The nature of the transformations and the rates at which they take place in the various radioactive series have been measured with great exactitude;

(3) The rate of radioactive disintegration of each of these elements is constant and independent of pressure, temperature and chemical constitution of the environments. Evidence for the constancy of the rate of disintegration is provided by pleochroic haloes—patterns of concentric rings—found in micas. A minute radioactive crystal is situated at the centre of each halo, and the various dark rings represent the end points of the ranges of α-particles of discrete energies shot out from the nuclei. The ranges are found to be the same in the haloes present in the oldest as well as the youngest micas.

The following is one of the important methods for the determination of geological time based on radioactivity :

Radioactive decay of the uranium-thorium series—During the processes of radioactive disintegration, the two isotopes of uranium (U^{238} and U^{235}) and the atoms of thorium eject a number of high energy α-particles (nucleii of helium atoms) until they finally end up as atoms of the common element lead. The reaction can be represented thus :

$$U^{238} \rightarrow Pb^{206} + 8\ He^{+}$$
$$U^{235} \rightarrow Pb^{207} + 7\ He^{+}$$
$$U(Th)^{232} \rightarrow Pb^{208} + 6\ He^{+}$$

It can be calculated that 1 g. of uranium yields (on an average) annually 1/7,600,000,000 g. of lead and accumulates 1.1×10^{-7} cc. of helium (at N.T.P.), assuming the whole of it is retained. The corresponding figures for thorium are 1/28,000,000,000 g. of lead and 3×10^{-8} cc. of helium.

Of the methods of determination of geological time based on radioactivity, the following two methods were adopted in the laboratories of the Physics Department, Indian Institute of Science, Bangalore, as part of the scheme on Age Determination of Igneous and Metamorphic Rocks of the Pre-Cambrian Era.

Alpha helium and radium-thorium methods

Alpha-helium method—The only source of helium found in rocks and minerals is constituted by the α-particles emitted from radioactive elements present in the specimen. The latter are the various members of the uranium, thorium and actino-uranium series. Since these members and their rates of disintegration are known the determination of uranium and thorium enables the total rate of production of α-particles to be evaluated.

There is a simpler and more direct method of evaluating the same quantity and this is the measurement of α-activity of the specimens. The mathematical relation between the total α-activity of a specimen, the amount of helium contained in it, and its geological age has been given by Evans and Goodman.

The "helium age" gives the actual geological age of the specimen only under the assumption that all the helium produced by radioactive disintegration has been retained by the specimen, i.e., if, the

helium retentivity of the specimen is unity. Unfortunately, a comparison of the helium ages with the corresponding "lead ages" (described below) has shown that, helium leakage does occur to an appreciable extent in most common rock minerals. This fact is understandable in the case of radioactive minerals in which the lattice is badly shattered by the high level of radioactivity and by the large amount of helium released leading to the building up of high internal pressures. In the case of ordinary rocks and minerals, the level of radioactivity (of the order of 1 α-particle/hr./mg.) and consequently the helium content (of the order of 10^{-5}cc./g. for a rock a few hundred million years old) are so low that even the best microscope fails to reveal cracks or fissures. Besides, theoretical calculations also reveal that the diffusion of helium through such crystal structures should be surprisingly low.

However, experimental results show that magnetite retains practically the whole of the helium produced; this is true for hornblende and a few other minerals. Close-grained basaltic rocks also retain a high percentage of the helium produced. Hence, magnetite crystals from selected localities were used in the investigations carried out in this laboratory. Experiments are also being carried out on fine-grained dyke-rock specimens belonging to the Deccan trap.

The helium apparatus, designed and set up in the laboratory, consists of: (a) a direct fusion furnace to melt the specimen and secure the release of helium; (b) a gas adsorption train to adsorb all gases except helium; and (c) a McLeod gauge into which helium is admitted and its volume measured.

The furnace contains an Acheson graphite plate which serves both as the heater element and as the crucible to hold the specimen. The resistor-crucible is contained inside a vacuum-tight, water-cooled furnace box. The heating current of 200-300 amp. is supplied from the secondary of a 20 kVA transformer (stepping down the voltage from 220 to 20), through water-cooled electrodes.

The adsorption train contains activated charcoal traps cooled to liquid air temperature. At this temperature, the charcoal adsorbs all the gases except helium. Only the adsorption of hydrogen is incomplete; hence the remaining gases are circulated with an admixture of oxygen over heated cupric oxide. The hydrogen is oxidized to water which with the remaining oxygen is adsorbed again.

The residual helium is admitted into the McLeod gauge where it is compressed into a calibrated capillary and the pressure measured. It is now a simple matter to calculate the volume of helium. The gas is sparked in the capillary to test its purity.

The total α-activity is measured in two ways, the results being mutually checked. The specimen is powdered and spread in an extremely thin layer inside a 4π α-counter designed for the purpose. This counts all the α-particles emitted (throughout the solid angle 4π). Applying some small corrections to allow for absorption and backscattering, the alpha index $=$ no. of α-particles emitted/hr./mg. of specimen is calculated.

Radium-thorium-helium method—This method depends on the measurement of uranium (or equivalent radium) and thorium. This

is done by fluxing the specimen in the direct fusion furnace and flushing out with argon, the evolved radon into a proportional counter. The radon gas is allowed to come into equilibrium with its decay products and its α-activity is measured. In thorium measurement, use is also made of the gaseous daughter element, thoron, but since this gas has an extremely short half-life (54.5 sec.), a streaming arrangement has to be adopted. In this procedure, the gas is formed by α-decay in a solution of thorium and is continually flushed with nitrogen or methane in a gas flow proportional counter which measures the α-activity. From the known decay rates of uranium and thorium, the α-activity can be calculated.

The helium age is given by $\frac{30.7 \times (\text{He})}{\text{alpha-index}}$ m.y.

where (He) = helium in 10^{-5}cc./g.

By the application of the alpha-helium method to magnetites from Holenarasipur schist belt, the age of the schist has been calculated as 1,700 m.y. The radium contents of a number of specimens from Kolar mines have also been determined.

The other and more reliable method depending on the radioactivity of uranium and thorium series is the lead method. The advantage of the latter method is that lead is more likely to be retained and to serve as an index of the age. However, the amount of lead found in ordinary rocks is so small that the method has been successfully applied only to radioactive minerals. Even here, it is necessary to distinguish between radiogenic lead and ordinary lead (non-radiogenic). The method of doing this is to carry out a mass-spectrometric analysis of lead and to find the relative abundances of different isotopes.

Since, at any given time, the rate of production of a particular radiogenic lead isotope depends only on the disintegration constant and the amount of parent present, the age of a mineral can be calculated from each of the ratios Pb^{206}/U, Pb^{207}/AcU, Pb^{208}/Th. Since uranium and actino-uranium are isotopes and the isotopic abundance ratio (U^{235}/U^{238}) is known, the age can be found from the ratio Pb^{207}/Pb^{206}. This ratio can be calculated from mass-spectroscopic data. The study of the hyperfine structure of some lead lines also leads to the evaluation of this ratio. If the mineral had remained unaltered, all the ratios should yield concordant values but this is rarely the case, because migrations of critical elements usually take place even in a fresh mineral. However, the method has the advantage that the relations between the ratios provide criteria for the assessment of the true age. Thus if the leakage of radon yields a lower value of Pb^{206}/U^{238}, then Pb^{207}/U^{235} provides a more correct value. The method based on the determination of Pb^{206}/Pb^{207} is more reliable, because any leaking would affect both uranium isotopes equally and the ratio remains unchanged.

Rubidium-strontium method

This method is based on the accumulation of the strontium isotope Sr^{88} in minerals by the β-decay of Rb^{87}. Since the half-life

of Rb^{87} is very long, one must have quite appreciable concentration of rubidium in order that measurable amounts of Sr^{88} may be formed during geological times. Further, it is desirable that the percentage of native strontium (Sr^{87}) be quite small, as otherwise a mass-spectroscopic examination of the isotopic abundance of the already small percentage of strontium becomes necessary. Fortunately, it is found that in potassium minerals crystallizing out of pegmatitic veins in the late hydrothermal or pneumatolytic stages, there is a very high degree of enrichment of rubidium and an equally high impoverishment of strontium. This fact is explained by the principles of geochemistry on the basis of ionic radii. A classic example is lepidolite which contains about 1 to 2 per cent of rubidium and in which the strontium is predominantly (99 per cent) radiogenic. Other minerals in which such a high degree of enrichment of radiogenic strontium is expected are phlogopite, hydrothermal microcline, and lithium-rich muscovite. The determination of rubidium and total strontium is effected by standard methods of spectrochemical analysis which have been improved and adopted for this problem by Ahrens and co-workers. The method is to photograph the arc spectrum of the specimen excited in a d.c. carbon arc. The characteristic lines due to rubidium and strontium can be identified. The quantitative analysis depends on the comparison of the intensity of a particular line of the analysis element with that of another line of the "internal standard" element, which is present in an invariable concentration. A "working curve" is prepared by plotting this intensity ratio as a function of the concentration of the analysis element, a series of standard matrices being prepared for this purpose. Phlogopite specimens from Travancore have been examined by this method and have yielded an age of about 1,500 m.y. The techniques are being improved and perfected, and the rubidium-strontium method can be expected to act as a valuable check and supplement to the lead and helium methods, especially in the dating of pre-Cambrian rocks.

IV

Palaeobotanical Investigations

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It is well known that sedimentary rocks like sandstone, shale and limestone, often contain fossils. A shale, for instance, is formed at the bottom of a water reservoir by the deposition of mud or clay, and remains of dead plants and animals may also sink down and become embedded in the deposit. The mud may harden to shale caused by the small mineral grains getting cemented to each other and it may be lifted up owing to the movements of earth's crust so as to become dry land or it may also become tilted, broken, or folded. The shale is layered, because the mud is not deposited continuously and uniformly throughout the year, but more in some seasons than in others. Therefore it can be split up in the way which is characteristic of shale, and one may find remains of the plants which were embedded in it on the bedding planes along which it splits. There may just be an impression and nothing more, but mostly the plant fragment also leaves some carbonised matter and sometimes the most resistant parts of the plant, the cuticle (a thin film covering the surface of the plant), may be found in such a state that they can be treated with chemicals and then studied under the microscope, sometimes revealing minute cell structures.

Other kinds of plant fossils are the petrifications, in which the plant organs have been impregnated with a solution of silica or other chemical matter which has prevented decay and transformed the plant organ into a stone, in which every cell wall is preserved and the anatomical structure can be studied if it is cut into thin sections and ground down to such thin slices that they let the light through. This is a type of fossil about which every palaeobotanist dreams, but it is much rarer than the impressions mentioned above.

Since early nineteenth century it has been known that the sedimentary rocks from the various periods in the history of the earth contain different fossils, while those of the same age often contain more or less the same species. As knowledge accumulated and information from all branches of geological science became available, it was possible to follow the evolution of plant (and animal) life and to characterise the flora of various periods so that from the composition

of the fossil flora in a certain sedimentary rock one could determine its age in the relative chronological system.

Fossils like the ones mentioned, which are called megafossils, are not found in all sedimentary rocks. The conditions at the time of formation of the rocks may have been such that no organic remains could be preserved. The decay may have been so fast that the remains may have become unrecognisable before fossilisation or they may have been destroyed afterwards due to pressure and changes in the rock. Even in such cases, it happens, however, that microfossils may be found.

By microfossils is meant all fossils that are so small that they can only be seen under the microscope. The most important plant microfossils are spores and pollen grains. Pollen is the powder, mostly yellow, that is found in the stamens of flowers. In many plants it is transported from the stamen of one flower to the stigma of another by means of insects. Other flowers, the wind-pollinated ones, just shed their pollen into the air, where it floats about, and out of the enormous number of pollen grains a few may land on the stigma of a flower of the same species. All the other pollen grains, and similarly the spores from ferns and other flowerless plants, slowly sink down and are deposited over the surface of the earth or water and may become embedded in clay or sand and in rocks arising from such sediments. The walls of spores and pollen grains consist of one of the most resistant organic compounds known, and they may, therefore, be found in sediments where all other organic matter has disappeared. Spores and pollen of different plants are different in size and shape, and with experience one may be able to recognise at least many of them through sufficient experience and careful and painstaking work.

Fossil spores were described as early as 1833 for the first time by Witham, although not correctly interpreted. It was not till the 1880's that the information concerning them was given on a broad and sound basis. In the last 30-40 years the knowledge of and interest in plant microfossils have increased enormously and their study now forms an important part of palaeobotanical research all over the world. It forms, in fact, the most characteristic trend in modern palaeobotany.

It happens quite frequently that microfossils may be found in rocks where the bigger fossils are missing or poorly preserved. They may, therefore, help in the dating of rocks where other fossils fail.

At the invitation of the Committee on Measurement of Geological Time in India, Professor Birbal Sahni drew out a plan in 1946 for research on the determination of the age of Indian sedimentary rocks containing microfossils but no megafossils. The plan was sanctioned in February 1947. An account of the work carried out in the Botany Department of the Lucknow University and later in the Birbal Sahni Institute of Palaeobotany is given below.

Materials and Methods

The problems studied were connected with the Saline series of the Salt Range (Punjab); the Blaini series; *Fermoria*, a problematic disc-like fossil from the Vindhyans; Darjeeling and Kashmir Gondwanas; Deoban limestone; Krols, Infra-Krols and Poonch Gondwanas.

The strata and localities selected were such that (1) the strata

Some microscopic fossils found embedded in sedimentary rocks : spores, wood fragments, cuticle (Greatly enlarged)

are not in their original position but have been folded, tilted and displaced and their stratigraphical position is open to question and (2) they are the oldest, e.g., the Vindhyans from which only very few fossils are known. Only those samples were collected from exact horizons that do not come from loose boulders and are available from places not exposed to air and are without cracks. This is to make sure that pollen and other plant matter from the atmosphere are avoided. The samples are immediately labelled and kept in numbered bags along with slips giving details about locality, date, etc. Some samples were obtained from the Geological Survey of India, Calcutta.

The rock specimens are thoroughly washed with distilled water and dried. They are further washed with alcohol and passed through a flame. Then they are kept in maceration jars, the latter also being thoroughly cleaned by distilled water and dried. In the jars the samples are treated with Schulze's solution (nitric acid, 60-70 per cent + potassium chlorate) for a fortnight or longer till the rock matrix is disintegrated and can be broken into fine pieces by means of a clean glass rod. When maceration is completed the acid is washed off with filtered distilled water under repeated centrifugation and decantation. The material is then treated with dilute ammonia to remove all traces of acid and to clarify the organic matter.

Of the residue, a smear is made on glass slides (3 in. $\times$ 1 in.) and dried in a drying box, then embedded in glycerine jelly, covered with a thin cover slip (22 x 40 mm. No. 0), and ringed with gold size. Thus 20-25 permanent slides are prepared for every material. Before use the slides and coverslips are washed with chromic acid and distilled water, cleaned with alcohol, and passed through a gas-flame. The slides are then examined in a microscope for microfossil contents.

Lately a somewhat different method has been introduced (adapted after Faegri and Iversen). It comprises, among other things, the use of hydrofluoric acid, washing with anhydrous acetic acid (9 parts) and concentrated sulphuric acid (1 part), repeated washing with potassium hydroxide, and washing. The residue is not dried before mounting.

The organic remains obtained are in the form of spores, pollen, cuticular and wood fragments, and sometimes animal remains. These organic remains are studied and compared with others which are always floating about in the atmosphere from known horizons.

The operations in the laboratory are carried out under conditions which avoid contamination of the materials by microscopic objects found in the air, such as spores, pollen and fragments of other plant matter. A number of slides are exposed to the air in the laboratory to serve as checks in the examination.

Results

In a sample of coal, or in fine-grained shale which has never been subjected to much pessure or heat, the pollen, spores and other plant microfossils may be abundant and well preserved. To examine such a sample is a long and tiresome job, but it is sure to give results; the observations and the conclusions drawn from them are as reliable as those based on megafossils.

On the other hand, conditions are far more difficult in palaeobotanical investigations of rock specimens. The material selected for investigation does not consist of specimens in which there are optimal chances for finding microfossils, abundant and well preserved. On the contrary, the material is just the types of rocks where other fossils have been destroyed or, more frequently, have never been present at all. The search for microfossils is a kind of last resort, a long shot which may hit, but more probably will not. It is not surprising, therefore, that the results in a great number of cases were negative.

The following positive and interesting results have been recorded:

(1) Confirmation for the view of those geologists who regard the Salt-pseudomorph bed as Cambrian as against the other view that they were Eocene.

(2) Inference that Magnesian Sandstone beds of the Salt Range are not Tertiary but Cambrian in age.

(3) Analysis of Neobolus shales of the Salt Range, Punjab also gave the same conclusion.

(4) Absence of any evidence to contradict the conclusion that the Vindhyan system is of very early Palaeozoic age.

(5) Confirmation of the opinion of eminent geologists that the Krol rocks are of Permo-Carboniferous age as a result of the examination of some Krol rocks of Simla near Subathu.

The following materials have been examined in the course of this study:

(1) Sample of Vindhyan shale from the lower part of Purple Sandstone, Nilwan Ravine, Salt Range.

(2) Vindhyan shale from Nimbahera District, Rajputana.

(3) Gondwana carbonaceous shale from Rajmahal Hills.

(4) Blaini rocks from Simla.

(5) Blaini rocks (6 localities) from Kosi area in Nepal.

(6) Blaini rocks (4 localities).

(7) Salt-pseudomorph beds, Salt Range, Punjab.

(8) Magnesian sandstone, Salt Range, Punjab.

(9) Neobolus shale, Punjab.

(10) Blaini rocks (8 localities).

(11) Infra-Krols (4 localities).

(12) Krol limestone.

APPENDIX

The following list gives, by way of illustration, the Geological Ages of a few of the rocks and minerals which have been so far determined in India by different methods. The list is incomplete as research on the subject is in progress at the Physics Departments of the Andhra University, Waltair, and the Indian Institute of Science, Bangalore.

Specimen	*Locality or Formation*	*Age (m. y.)*
HELIUM RATIO		
Magnetite crystals	Holenarasipur, Mysore	1,700
Magnetite bearing charnockite schist	Holenarasipur, Mysore	1,600
Magnetite, Junagadh	Kathiawar, Bombay	1,650
Quartz-magnetite	Kanjamalai, Madras	1,500
Pyroxenites	Kanjamalai, Madras	1,300
Quartz-magnetite	Ongole, Andhra	1,350
Hornblende-schist	Nandydurg, Mysore	1,400
Hornblende-schist (felspathised)	Holenarasipur, Mysore	1,100
Quartz vein	Kolar, Mysore	600
Pink feldspar	Nellore, Andhra	500
Garnetiferous pegmatite	Iddapadi, Madras	400
RUBIDIUM—STRONTIUM RATIO		
Phlogopite	Colachel, Travancore	1,650
Phlogopite	Near Visakhapatnam, Andhra	1,600
URANIUM—LEAD RATIO		
Samarskite	Nellore (Archaean)	$1,600 \pm 50$
Aravalli System	(Dharwar)	1,600
Upper Shillong Series	(Purana)	955 ± 40
Delhi System	(Purana)	735
Allanite	Chhota Nagpur (Purana)	837
Allanite	Eastern Ghats (Dharwar)	1,560

Due date	*Return Date*	*Due Date*	*Return Date*

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